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(54) Title: DATA TRANSFER METHOD AND APPARATUS
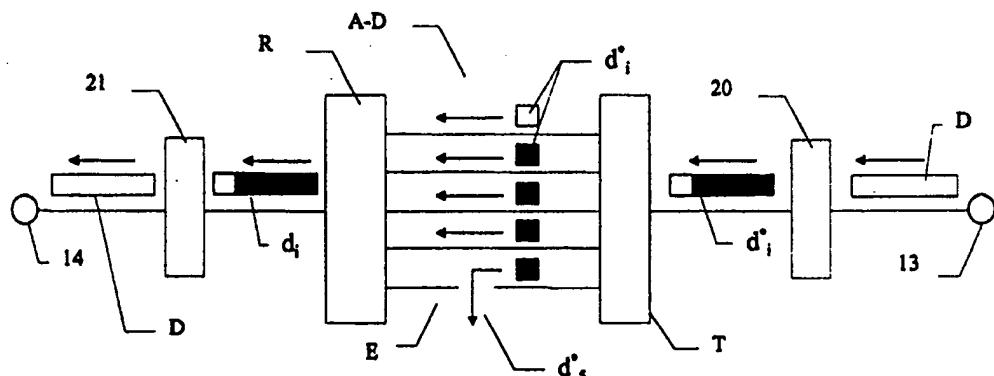
(57) Abstract

A method of and apparatus for transferring data between a source and a destination where there are plural communication paths between the source and the destination are provided. The data is divided into m discrete units each containing a portion of the data. The m discrete units are transformed into m+n transformed data units where n≥1. Each of said m+n transformed data units is transmitted from said source over the paths such that at least two paths are used for the transmission of the transformed data units from the source. The data is reconstructed from at least m transformed data units received at the destination.

DATA TRANSFER METHOD AND APPARATUS

The present invention relates to a data transfer
method and apparatus.

In our International patent application no.
PCT/GB97/03472 and our British patent application no.
9726873.4, the entire disclosures of which are incorporated
herein by reference, there is disclosed a communications
apparatus comprising a mesh of interconnected nodes. Each
node can communicate with plural other nodes via point-to-
point radio links between nodes by means of substantially
unidirectional radio transmissions along the links. In a
typical example, each node has eight links providing a
connection from each node to eight other nodes. Time
division duplex (TDD) is used to alternate transmission and
reception modes along a link. In a preferred embodiment,
time division multiplexing (TDM) is used to control the
timing of transmission and reception between the links.
For example, a node is able to transmit along a first link
in a first time slot of a transmission portion of a time
frame, along a second link during the second time slot of
the transmission portion of the time frame, etc., for eight
transmission time slots for the eight links. The node then
is able to receive along the first link during a first time
slot of the reception portion of the time frame, along the
second link during the second time slot of the reception
portion of the time frame, etc., for eight reception time
slots for the eight links. As an alternative to TDM,
frequency division multiplexing (FDM) or other techniques
such as code division multiple access (CDMA) may be used.

In our PCT/GB97/03472 and our British patent
application no. 9726873.4, it was broadly described how a
benefit of the communications apparatus is that there are
normally plural choices of path for communicating between
any particular pair of nodes. The present invention

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relates to a method and apparatus for exploiting this
feature in order to provide highly reliable communication
between nodes.

5   According to a first aspect of the present invention,
there is provided a method of transferring data between a
source and a destination where there are plural
communication paths between the source and the destination,
the method comprising the steps of: dividing the data into
10   m discrete units each containing a portion of the data;
transforming said m discrete units into m+n transformed
data units where n≥1; transmitting each of said m+n
transformed data units from said source over the paths such
that at least two paths are used for the transmission of
15   the transformed data units from the source; receiving at
least some of the transformed data units at the
destination; and, if at least m transformed data units are
received at the destination, reconstructing at the
destination the data from at least m transformed data units
20   received at the destination.

       The present invention provides for highly reliable
transmission of data between a source and a destination by
taking advantage of the possibility of using multiple paths
25   for the circuit set up between the source and the
destination. This is achieved without requiring
unrealistic levels of reliability of the individual paths
themselves. This is particularly advantageous in a
wireless transmission system.
30
       There are preferably at least m+n transmission paths
between the source and the destination and the transmitting
step preferably comprises transmitting each of said m+n
transformed data units from said source over a different
35   one of the paths.

The m discrete data units preferably each contain a different portion of the data. This leads to increased efficiency of data transfer because the minimum amount of bandwidth is used as there is no repetition of data across the discrete data units.

The method may comprise the step of sending an error signal to the source to indicate transmission failure if less than m transformed data units are received at the destination after a predetermined time has elapsed after said transmitting step.

The transmission may be a wireless transmission.

In a preferred embodiment, each of the paths is formed from at least one point-to-point wireless transmission link between the source and the destination.

According to a second aspect of the present invention, there is provided apparatus for transferring data between a source and a destination where there are plural communication paths between the source and the destination, the apparatus comprising: a divider for dividing the data into m discrete units each containing a portion of the data; means for transforming said m discrete units into m+n transformed data units where n≥1; a transmitter for transmitting each of said m+n transformed data units from said source over the paths such that at least two paths are used for the transmission of the transformed data units from the source; a receiver for receiving at least some of the transformed data units at the destination; and, means for reconstructing at the destination the data from at least m transformed data units received at the destination if at least m transformed data units are received at the destination.

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The transmitter is preferably arranged to transmit
each of said m+n transformed data units from said source
over a different one of the paths.

5   The divider is preferably arranged to divide the data
such that each of the m discrete data units contains a
different portion of the data.

Means may be provided for sending an error signal to
10   the source to indicate transmission failure if less than m
transformed data units are received at the destination
after a predetermined time has elapsed after said
transmitting step.

15   The transmitter may be arranged to transmit wireless
transmissions.

In a preferred embodiment, each of the paths is formed
from at least one point-to-point wireless transmission link
20   between the source and the destination.

An embodiment of the present invention will now be
described by way of example with reference to the
accompanying drawings, in which:

25

Fig. 1 shows schematically a conventional transmission
circuit from one node to another according to the prior
art;

30   Fig. 2 shows schematically a transmission circuit in
accordance with an example of the present invention; and,

Fig. 3 is a schematic representation of the division,
transformation, transmission, reception and reconstruction
35   of a piece of user data in accordance with the present
invention.

Referring to Figure 1, there is shown a first
subscriber at a first node 1 who wishes to transfer data to
a second subscriber at a second node 2. To achieve this, a
virtual or logical circuit 3 is set up between the two
5   nodes 1,2. (It will be appreciated by those skilled in the
art that the following description and the present
invention can easily be applied to "connectionless" data
traffic also.) The virtual circuit 3 is constructed from
several links 4, in general K links 4, via intermediate
10 nodes 5 between the nodes 1,2 between which data is to be
transmitted. The links 4 between the nodes 1,2 between
which data is to be transmitted are connected in series.
Thus, if the probability that a particular link 4 is
available for transmission is P_{avail}, then the probability of
15 the circuit 3 being available is $1-K(1-P_{avail})$ as only one
link 4 needs to fail for the circuit 3 to be lost
completely, assuming any link failures are uncorrelated.
This is true whether the links 4 are wired or wireless or a
mixture of wired and wireless.
20

Referring to Figure 2, there is shown a portion of a
communications network 10 in accordance with the
communication apparatus disclosed in our PCT/GB97/03472 and
our British patent application no. 9726873.4. There are
25 many nodes 11 which are each logically connected to other
nodes 11 by point-to-point wireless transmission links 12
using substantially unidirectional wireless transmissions,
i.e. signals are not broadcast but are instead directed to
a particular node with signals being capable of being
30 passed in both directions along the link 12. In the
example shown in Figure 2, it is assumed that one of the
nodes 13 wishes to transmit data to another node 14. This
may be achieved by constructing a logical or virtual
circuit 15 between the two nodes 13,14 between which data
35 is to be transferred. The circuit 15 in the specific
example shown in Figure 2 is constructed from four
different paths A, B, C, D. Each of the transmission paths

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A-D follows a different route via different nodes 11. As
will be discussed further below, the actual number of paths
chosen to form the circuit 15 can vary enormously depending
on the data to be transferred, the reliability of service
required, and the data traffic loading of the network 10 as
a whole. Only the links 12 between nodes 11 actually being
used for carrying traffic between the nodes 13,14 are shown
in Figure 2.

As with the prior art example shown in Figure 1, the
probability that a particular path A-D is available for
transmission is the probability that a particular link 12
is available, i.e. P_{avail}(path) = $1-K(1-P_{avail}$(link on path)).

A piece of data D which is intended for transmission
from one node 13 to another node 14 across the network 10
can be split into m separate fragments or units
$\{d_i$, i=1 to m$\}$. In accordance with the present invention,
the m discrete data units d_i are transformed by an
appropriate algorithm into m+1 transformed data units
$\{d*_i$, i=1 to m+1$\}$. The transformation from the original
data units d_i to the transformed data units $d*_i$ is such that
the m original data units d_i can be reconstructed from any m
of the transformed data units $d*_i$.

As a simple example, the transformation from the
discrete data units d_i into the transformed data units $d*_i$
can be by means of an appropriate arbitrary matrix C which,
in this example, is a m x m+1 matrix. Thus, $d*_i = C_{ij}.d_j$.
In this example, all of the m original data units d_i can be
computed exactly from any m of the transformed data units
$d*_j$ by making the square m x m matrix C'_{ij} from the columns
of the transformation matrix C_{ij} which correspond to the
particular m transformed data units $d*_i$ and using its
inverse C'^{-1}.

For example, if m = 4, then $C = \{c_1\ c_2\ c_3\ c_4\ c_5\}$, where the c_i are each four-element column vectors. The original piece of data D can be reconstructed from for example the received fragments $\{d*_1\ d*_2\ d*_3\ d*_5\}$, that is using all

5　transformed data units $d*_i$ except for $d*_4$, by the reconstruction $d = C'^{-1}.d*$ where the reconstruction matrix C' is formed from the column vectors of the transformation matrix C except for the column vector corresponding to the absent transformed data unit $d*_i$, i.e. here C' =

10　$\{c_1\ c_2\ c_3\ c_5\}$, and C'^{-1} is the inverse matrix of C'.

Now, suppose that for every piece of user data D = $\{d_i,\ i=1\ \text{to}\ m\}$ to be transmitted between a pair of nodes 13,14 there is formed a transformed version of the data D*

15　= $\{d*_i,\ i=1\ \text{to}\ m+1\}$ and that each transformed data unit $d*_i$ is sent over a different one of m+1 paths A-D constituting a circuit 15 as indicated by way of example in Figure 2. If a particular link 12 of a path j is unavailable thereby resulting in the loss of the transformed data unit $d*_j$

20　transmitted on that path j, the original piece of user data D can still be reconstructed at the receiving node 14 assuming that the transformation matrix C is known to the destination node 14 as well as to the source node 13.

25　This is indicated schematically in Figure 3. The source node 13 produces a piece of user data D, which may be for example a data packet. The user data D is divided at 20 by appropriate means, such as for example a computer running appropriate software, into m discrete data units

30　$\{d_i,\ i=1\ \text{to}\ m\}$. In this example, m = 4. The m discrete data units $\{d_i,\ i=1\ \text{to}\ m\}$ are then transformed at 20, by for example a computer running appropriate software, into m+1 (here 5) transformed data units $\{d*_i,\ i=1\ \text{to}\ m+1\}$. By way of example, the transformation may be carried out using

35　a transformation matrix C as discussed above. The m+1 transformed data units $d*_i$ are transmitted at T by the node 13 over the circuit 15 with each of the individual

transformed data units $d*_i$ being transmitted over a
different one of the m+1 paths A-E. As can be seen, the
transformed data unit $d*_5$ transmitted on path E is lost
during transmission because, for example, one of the links
5   12 on path E has failed. Thus, in the example shown in
Figure 3, only the first four transformed data units $d*_1$,
$d*_2$, $d*_3$, and $d*_4$ are received at R by the destination node
14. At R, the four received transformed data units $d*_1$,
$d*_2$, $d*_3$, and $d*_4$ can be acted upon, by for example a
10 computer running appropriate software with an appropriate
algorithm, to regenerate all of the m original data units
$\{d_i$, i=1 to m$\}$ even though the transformed data unit $d*_5$
transmitted on path E was lost and only m transformed data
units $d*_i$ were received. In the specific example described,
15 the reconstruction of the original discrete data units d_i
from the subset of transformed data units $d*_i$ actually
received is made using the inverse matrix C'^{-1} where the
reconstruction matrix C' is formed from the transformation
matrix C used at 20 but without the column (here the fifth
20 column) which relates to the transformed data unit which
has been lost (here the fifth transformed data unit $d*_5$).
The complete set of reconstructed data units d_i are passed
to a buffer 21 associated with the destination node 14.
The buffer 21 stores and reassembles the discrete data
25 units d_i, taking into account the fact that different
transformed data units $d*_i$ will have been received at
different times according to the length of the particular
transmission path A-D traversed by that transformed data
unit $d*_i$ such that transformed data units $d*_i$ can be
30 received out of sequence, thereby to reconstruct the
original data D for the destination node 14.

In this method, where the m original data units d_i are
transformed into m+1 transformed data units for
35 transmission, a circuit 15 will only be lost (i.e. the
original piece of user data D is not effectively received)

if at least two separate paths A-E have an unavailable link
12.

In general, a piece of user data D can be split into m
discrete data units $\{d_i, i=1 \text{ to } m\}$. The m discrete data
units $\{d_i, i=1 \text{ to } m\}$ can be transformed into m+n transformed
data units $\{d^*_i, i=1 \text{ to } m+n\}$ where $n \geq 1$.

In general, the availability of a link $P_{avail}(\text{link})$ in
this scheme can be related to the required circuit
availability P_{avail} by:

$$P_{avail}(\text{link}) := 1 - \frac{\left(\dfrac{1 - P_{avail}}{W(m,n)}\right)^{\frac{1}{(n+1)}}}{K}$$

where:

$$W(m,n) := \frac{(m+n)!}{(m-1)! \cdot (n+1)!}$$

and K is the mean number of links per path.

To put this into context, if the required circuit
availability is 99.997%, i.e. a circuit is unavailable for
only 15.8 minutes per year, then with conventional
transmission networks as shown in Figure 1, the
availability of each link must be 99.99925% where K=4, i.e.
there are four links, which is equivalent to a link
unavailability of only about 4 minutes per year, meaning
that the link availability must be much greater than the
overall required circuit availability.

In the specific example of the present invention
discussed above, where n=1, the probability of losing a
link on an individual path A-D need only be 99.9965% (from
the above expression with m=4, n=1, K=5) to achieve the
same circuit reliability of 99.997%. This is equivalent to
a link unavailability of over 3 hours per year. This means

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that, in the simple example shown above where the m
discrete data units d_i into which the original piece of user
data D is initially fragmented are transformed into m+1
transformed data units $d*_i$, the transmission circuits 15
5   which can be set up in accordance with the present
invention have an availability (which is equivalent to
reliability) which is approximately 11.6 times better than
the availability of an individual link 12. This means that
a wireless transmission network using the present invention
10 can have a reliability and availability which is
practically the same as available with conventional wired-
networks and which far exceeds that available with
conventional wireless networks assuming that the mean
number of links per path does not become excessive.

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      If for example n=2 so that up to two paths of a
circuit can be lost without there being a complete loss of
data, then 99.997% circuit availability can be achieved
with individual link availabilities of 99.771%, which is
20 equivalent to an unavailability of 20 hours per year. This
is equivalent to a decrease in the reliability of a link of
a factor of nearly eighty compared to the overall
reliability and availability of the circuit 15. In other
words, the reliability required of any one transmission
25 link is in principle very much less stringent when the
present invention is implemented to transmit data.

      It will be appreciated that this improved resilience
requires that more data in total is always sent over the
30 network 10 than is actually present in the original data D.
For example, in the example described above, if the
original piece of user data D is L bytes long, each
original data unit d_i is L/m bytes, and each transformed
data unit $d*_i$ is also L/m bytes long. Hence, if the m+n
35 transformed units $d*_i$ are sent over m+n different paths, a
total of L(m+n)/m bytes are sent. Thus, n-fold resilience
requires (m+n)/m times the bandwidth of a circuit

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constructed from a single path. Clearly, to reduce this
bandwidth overhead it is desirable to make m as large as
possible compared to n so that the bandwidth overhead
factor tends to 1. However, in a multi-user network,

5 allocating independent paths to a single circuit becomes
more difficult and resource intensive as the number of
paths per circuit increases. A compromise between
minimising the number of paths per circuit and maximising
the fragmentation of the message should normally be

10 reached. This compromise will mainly depend on the degree
of resilience required of a particular circuit given the
availability of the individual radio transmission links in
the system and the instantaneous traffic load in the
system. For example, in a lightly loaded system, it will

15 normally be more straightforward to allocate a large number
of paths to a circuit than in a heavily loaded system.

As an example, if data D were split into four
fragments, from which five transformed fragments were sent

20 over five different paths on one circuit, this circuit
would be 11.6 times more reliable than the individual links
and would use 25% more bandwidth than a single path
circuit. Transforming the data D into six fragments would
provide over 77 times the individual link reliability, for

25 50% more bandwidth. Thus, this multipath-per-circuit
feature allows the network operator to provide very high-
reliability circuits on demand for modest bandwidth
overheads as the reliability increases very much more
rapidly than the bandwidth overhead.

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This technique is well-suited to radio systems where
radio transmission links can be impaired with high
probability owing to environmental effects such as
electrical interference, weather, physical obstructions

35 (which may be temporary such as passing vehicles or more
permanent such as growing trees or erection of new
buildings), etc. It will be appreciated that it can also

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be used in wired links, though the cost of providing multiple wired connections to subscribers is likely to be prohibitive in most circumstances.

5   The following describes a method for implementing the above technique.

Suppose a user at a source node 13 wishes to connect to a user at a destination node 14 with a transmission
10   reliability R. A controller, which may be associated with the source node 13 or which may be an overall system controller for example, computes the number of paths N required to achieve R and the fragmentation factor m given the current bandwidth overhead tolerable and the current
15   worst link reliability R_{link} using the method outlined above.

The system then attempts to set up N independent paths from node 13 to node 14. The result of this is that N' paths can in fact be set up where N' ≤ N because of the
20   existing system usage.

If N' is below a threshold, then the system will return a "circuit unavailable" message back to the user.

25   If N' is satisfactory, then the expected maximum transit time T2 along each of the paths is computed. If this value is incompatible with the traffic type requirements for any of the paths, those paths are rejected. If the remaining number of paths is below the
30   threshold number, a "circuit unavailable" message is returned to the user; if not, then the controller signals to the destination node 14 that N"(that is, the remaining number of paths with satisfactory time delays) transformed data units are to be received on this circuit. The
35   transmission can then proceed.

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The user at source node 13 then sends a piece of user
data D to the controller in the source node 13. This piece
of user data D is fragmented into m discrete units d_i and
transformed into N″ new units $d*_i$. Each of these
5 transformed data units $d*_i$ is sent to the destination node
14 each on a different path.

At the destination node 14, the node controller reads
received transformed data units $d*_i$ from the N″ paths and
10 buffers according to the following scheme:

1.   At time T1 after receipt of the first transformed data
unit, if all N″ transformed data units $d*_i$ have been
received, then the user data D is reconstructed from the
15 input buffer.

2.   If at T1, n (< N″) transformed data units $d*_i$ have been
received, and n = N″ - m, then all of the original data
units d_i are reconstructed from the n received transformed
20 data units $d*_i$ and buffered and the user data D is
reconstructed from the now complete buffer.

3.   If after time T2 after receipt of the first
transformed data unit (where T2 > T1), N″-m transformed
25 data units have been received, then the missing data units
are reconstructed as in the previous step. If this is not
the case, then the missing data units are assumed lost and
an errored data packet is reconstructed and sent to the
user at the source node 13.
30

This is repeated for each piece of data D sent from
the source node 13 to the destination node 14 (and vice
versa) until either party terminates the transmission.
Upon transmission termination, when the last data unit has
35 been received, all the paths in the circuit are cleared
down by the system.

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Normally the parameter T2 must be less than the
message reception time-out period of the upper-level
protocol (i.e. that being used by nodes 13,14 to
communicate). The parameter T1 will be related to the
5 latency of the paths given the current network loading.

An embodiment of the present invention has been
described with particular reference to the examples
illustrated. However, it will be appreciated that
10 variations and modifications may be made to the examples
described within the scope of the present invention.

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CLAIMS

1. A method of transferring data between a source and a
destination where there are plural communication paths
5   between the source and the destination, the method
comprising the steps of:
    dividing the data into m discrete units each
containing a portion of the data;
    transforming said m discrete units into m+n
10 transformed data units where n≥1;
    transmitting each of said m+n transformed data units
from said source over the paths such that at least two
paths are used for the transmission of the transformed data
units from the source;
15   receiving at least some of the transformed data units
at the destination; and,
    if at least m transformed data units are received at
the destination, reconstructing at the destination the data
from at least m transformed data units received at the
20 destination.

2. A method according to claim 1, wherein there are at
least m+n transmission paths between the source and the
destination, the transmitting step comprising transmitting
25 each of said m+n transformed data units from said source
over a different one of the paths.

3. A method according to claim 1 or claim 2, wherein the
m discrete data units each contain a different portion of
30 the data.

4. A method according to any of claims 1 to 3, comprising
the step of sending an error signal to the source to
indicate transmission failure if less than m transformed
35 data units are received at the destination after a
predetermined time has elapsed after said transmitting
step.

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5.   A method according to any of claims 1 to 4, wherein
the transmission is a wireless transmission.

6.   A method according to any of claims 1 to 5, wherein
each of the paths is formed from at least one point-to-
point wireless transmission link between the source and the
destination.

7.   Apparatus for transferring data between a source and
a destination where there are plural communication paths
between the source and the destination, the apparatus
comprising:
        a divider for dividing the data into m discrete units
each containing a portion of the data;
        means for transforming said m discrete units into m+n
transformed data units where n≥1;
        a transmitter for transmitting each of said m+n
transformed data units from said source over the paths such
that at least two paths are used for the transmission of
the transformed data units from the source;
        a receiver for receiving at least some of the
transformed data units at the destination; and,
        means for reconstructing at the destination the data
from at least m transformed data units received at the
destination if at least m transformed data units are
received at the destination.

8.   Apparatus according to claim 7, wherein the
transmitter is arranged to transmit each of said m+n
transformed data units from said source over a different
one of the paths.

9.   Apparatus according to claim 7 or claim 8, wherein the
divider is arranged to divide the data such that each of
the m discrete data units contains a different portion of
the data.

10. Apparatus according to any of claims 7 to 9, comprising means for sending an error signal to the source to indicate transmission failure if less than m transformed
5 data units are received at the destination after a predetermined time has elapsed after said transmitting step.

11. Apparatus according to any of claims 7 to 10, wherein
10 the transmitter is arranged to transmit wireless transmissions.

12. Apparatus according to any of claims 7 to 11, wherein each of the paths is formed from at least one point-to-point wireless transmission link between the source and the destination.

PRIOR ART
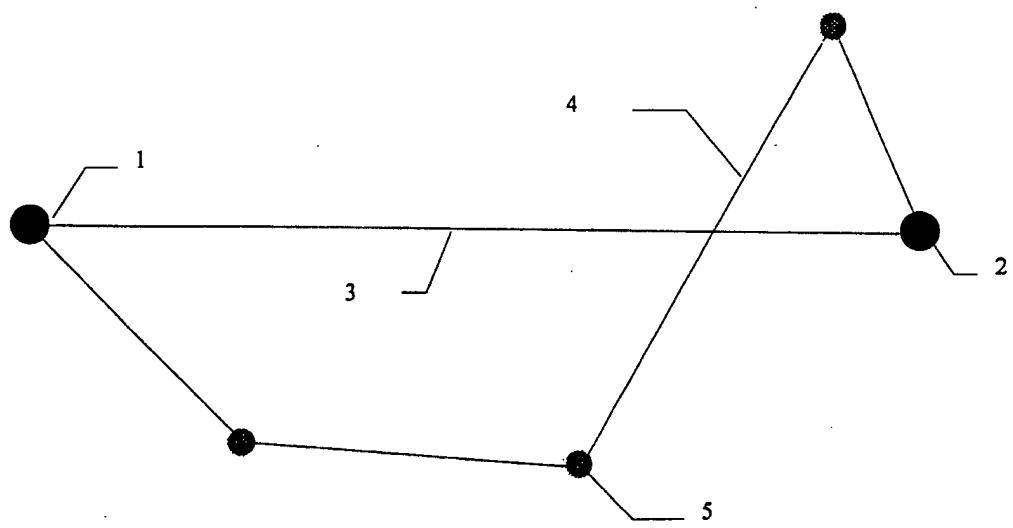
Figure 1

2/2
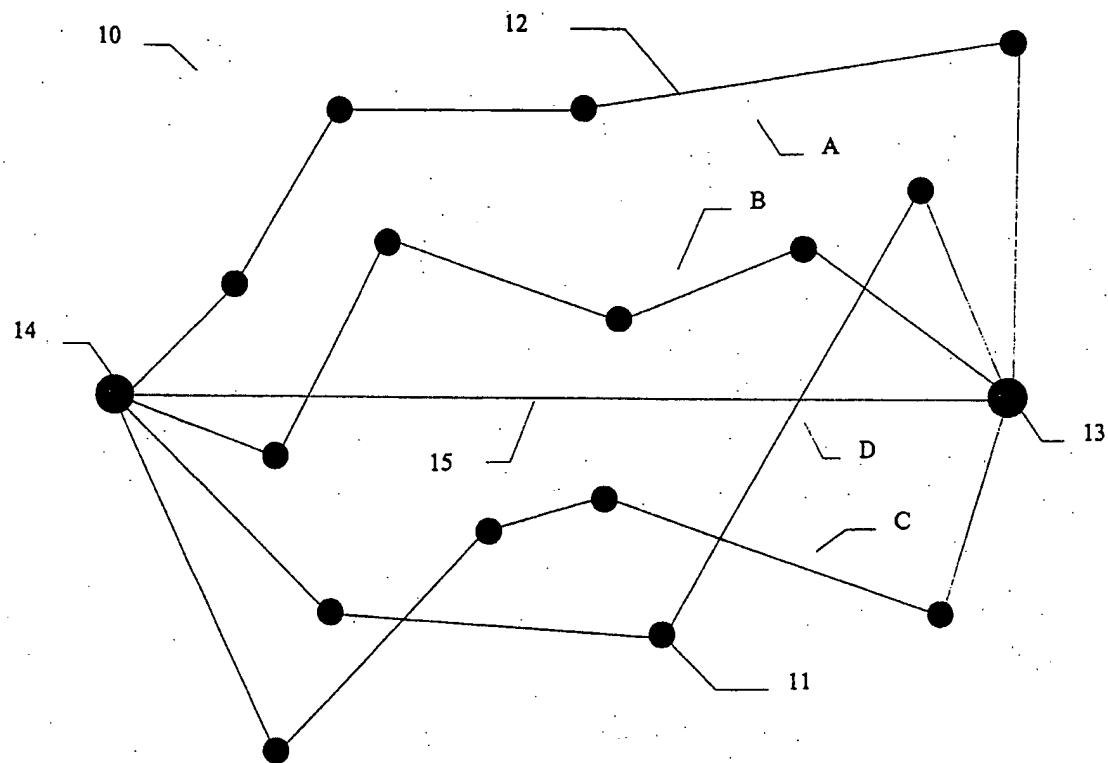
Figure 2
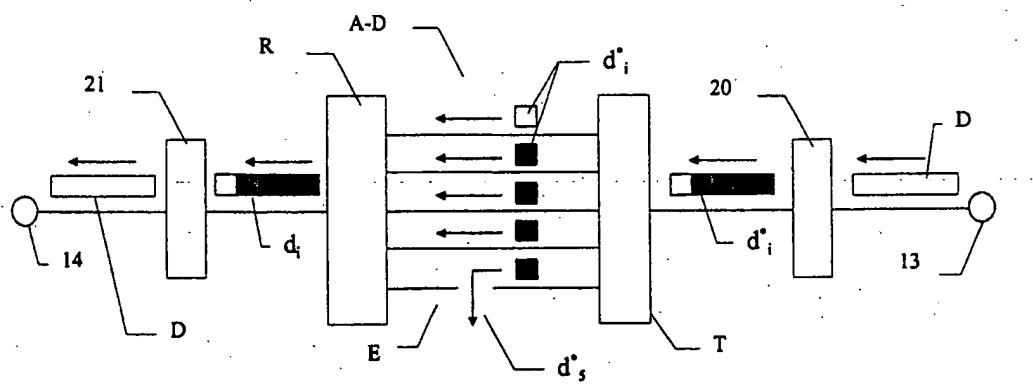
Figure 3

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H04L29/04   H04L12/56   H04L29/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MAXEMCHUK N F: "DISPERSITY ROUTING IN HIGH-SPEED NETWORKS" COMPUTER NETWORKS AND ISDN SYSTEMS, vol. 25, 1 January 1993 (1993-01-01), pages 645-661, XP000570119 ISSN: 0169-7552 abstract page 645, left-hand column, paragraphs 1,2 page 646, right-hand column, paragraph 3 -page 648, left-hand column, paragraph 1 page 651, right-hand column, paragraph 4 -page 652, left-hand column, paragraph 4 page 654, left-hand column, paragraph 2 page 659, right-hand column, paragraph 1 --- -/--	1-12

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 October 1999	05/11/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Blanco Cardona, P

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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